E6L27
12
UNCLASSIFIED

NACA
CLASSIFICATION CANCELLED

RM No. E6L27

E6L27
25A

NACA

RESEARCH MEMORANDUM

9696-A

for the

Air Materiel Command, Army Air Forces

EFFECT OF MODIFICATIONS TO INDUCTION SYSTEM ON ALTITUDE PERFORMANCE OF V-1710-93 ENGINE

III - USE OF PARABOLIC ROTATING GUIDE VANES AND NACA-DESIGNED AUXILIARY-STAGE INLET ELBOW AND INTERSTAGE DUCT

By Ray M. Standahar and James S. McCarty

Aircraft Engine Research Laboratory
Cleveland, Ohio

TECHNICAL LIBRARY
AIRESEARCH MANUFACTURING CO.
9851-9951 SEPULVEDA BLVD.
INGLEWOOD, CALIFORNIA

CLASSIFIED DOCUMENT

This document contains classified information affecting the National Defense of the United States within the meaning of the Espionage Act, USC 50:31 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law. Information so classified may be imparted only to persons in the military and naval Services of the United States, appropriate civilian officers and employees of the Federal Government who have a legitimate interest therein, and to United States citizens of known loyalty and discretion who of necessity must be informed thereof.

CONTAINS PROPRIETARY INFORMATION

TECHNICAL EDITING WAIVED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

JANUARY 16 1947

NACA
CLASSIFICATION CANCELLED

UNCLASSIFIED

CLASSIFICATION CANCELLED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

EFFECT OF MODIFICATIONS TO INDUCTION SYSTEM ON ALTITUDE PERFORMANCE OF V-1710-93 ENGINE

III - USE OF PARABOLIC ROTATING GUIDE VANES AND NACA-DESIGNED AUXILIARY-STAGE INLET ELBOW AND INTERSTAGE DUCT

By Ray M. Standahar and James S. McCarty

SUMMARY

Bench runs of a modified V-1710-93 engine equipped with a two-stage supercharger, interstage carburetor, aftercooler assembly, and backfire screens have been made at a simulated altitude of 29,000 feet to determine the effect of several induction-system modifications on the engine and supercharger performance. The standard guide vanes on the auxiliary- and engine-stage superchargers were replaced by rotating guide vanes with a parabolic blade profile. The auxiliary-stage inlet elbow and interstage duct were replaced with new units of NACA design. These modifications were made one at a time and data were obtained after each change to determine the effect of each modification. All runs were made at a constant engine speed of 3000 rpm at a simulated altitude of 29,000 feet and all changes in engine power were made by varying the speed of the auxiliary-stage supercharger.

Modifying the engine by incorporating backfire screens and by using parabolic rotating guide vanes on both superchargers gave no over-all power increase. Although the performance of the auxiliary-stage supercharger was improved, this gain was nullified by the pressure drop through the backfire screens and by the concurrent decrease in performance of the engine-stage supercharger. Replacing the standard Bell inlet elbow with one designed by the NACA, resulted in a power increase of about 15 brake horsepower. This power increase

RESTRICTED

can be attributed to the fact that the pressure losses in the NACA-designed inlet elbow were approximately one-half those for the standard Bell elbow. The use of the NACA-designed interstage duct together with the other modifications gave an over-all power increase of about 25 brake horsepower.

INTRODUCTION

At the request of the Army Air Forces, Air Materiel Command, an investigation has been conducted at the NACA Cleveland laboratory to improve the altitude performance of the V-1710-93 engine equipped with a two-stage supercharger. A substantial increase in engine power has been realized by increasing the auxiliary-stage gear ratio from 6.85:1 to 8.08:1, by changing to interstage carburetion, and by providing an aftercooler and methods for internal-coolant injection (reference 1). A slight gain in engine power was obtained by increasing the engine speed from 3000 to 3200 rpm (reference 2). A further step in the program was an attempt to improve the individual performance of the superchargers and to reduce the pressure losses through the induction system, thereby increasing the over-all engine performance.

Previous analysis and manufacturer's tests indicated that an appreciable gain in engine power could be obtained with the addition of parabolic rotating guide vanes on the superchargers and with a redesign of the supercharger ducting to allow for a lower pressure loss than was obtained from the standard ducting. Three modifications were therefore made on the supercharger and induction system to improve the performance of the engine; parabolic rotating guide vanes replaced the standard units on each supercharger, an NACA-designed auxiliary-stage supercharger inlet elbow was used, and an NACA-designed interstage duct was installed. Backfire screens were installed downstream of each aftercooler to protect the engine during this investigation. Because the pressure drop through these screens was large, the full potentialities of the other modifications could not be fully realized with the present setup. The modifications were made one at a time and a series of runs were made after each change to determine separately the effect of each modification. Because of the sequence of the investigations, the data from runs with the third modification showed the combined effects of all the changes. The effectiveness of these modifications in increasing engine performance at a simulated altitude of 29,000 feet and an engine speed of 3000 rpm is presented.

RESTRICTED

RESTRICTED

APPARATUS AND PROCEDURE

The V-1710 engine used for this investigation was the same as the engine described in reference 1. Because of the backfiring experienced during the investigations of references 1 and 2, the engine was modified by placing backfire screens immediately downstream of each aftercooler unit to lessen the possibility of damaging the cooler units. An over-all view of the entire setup is presented in figure 1 and a view of the induction system and instrumentation in figure 2. Figure 3 shows a backfire screen mounted in the aftercooler-outlet duct.

A photograph of one of the parabolic rotating guide vanes that replaced the standard guide vanes on both superchargers for this investigation is shown in figure 4 together with a photograph of a standard guide vane. The manufacturer's tests of superchargers equipped with parabolic rotating guide vanes indicated that the efficiency of the superchargers would be improved with a resulting increase in engine performance.

Two series of runs were made to determine the effect of a reduced pressure loss in the induction system on engine performance. The standard Bell inlet elbow for the auxiliary-stage supercharger was replaced by a new inlet elbow of NACA design for the second series of runs. These elbows are completely described in reference 3. For the third and final series, the engine was further modified by replacing the standard interstage duct (fig. 5(a)) with a new duct of NACA design (fig. 5(b)).

The values of the inlet pressure and temperature for all runs were 11.5 inches of mercury absolute and -14° F, respectively. These values correspond to ram conditions at an altitude of 29,000 feet. The ram conditions were determined for an assumed airplane velocity of 435 miles per hour and 100-percent recovery of the temperature rise and 75-percent recovery of the velocity pressure in the intake air scoop.

Data were obtained for a range of auxiliary-stage supercharger tip speeds from approximately 780 feet per second to the maximum speed obtainable. No lower tip speeds were investigated because they are not in the normal operating range of the engine. The following engine conditions were held constant for all runs:

RESTRICTED

RESTRICTED

Engine speed, rpm	3000 ±10
Engine coolant-out temperature, °F	250 ±10
Oil-in temperature, °F	170 ±10
Throttle setting	Wide open
Fuel-air ratio	0.080 ±0.003
Aftercooler coolant-in temperature, °F	105 ±5

With one exception, the instrumentation for this investigation was the same as that of reference 1. The inlet station of the engine-stage supercharger varied slightly owing to the different design of the interstage duct. Pressure and temperature readings were taken ahead of and behind each supercharger so the individual as well as the over-all supercharger performance could be calculated. All supercharger-performance calculations were made in accordance with the methods given in reference 4. The values of the engine-stage and over-all adiabatic efficiency and temperature rise are to be used only as trends inasmuch as a constant correction factor of 50° F was added to the measured manifold temperature to account for the temperature drop due to the evaporation of fuel.

RESULTS AND DISCUSSION

Engine Performance

The relation among brake horsepower, manifold pressure, and auxiliary-stage tip speed for various modifications is shown in figure 6. A maximum of 1296 brake horsepower was reached at an auxiliary-stage tip speed of 1235 feet per second during the investigation of the effect of parabolic rotating guide vanes. This value is approximately 14 brake horsepower lower than the maximum power obtained in reference 1. This decrease in power is probably the result of the pressure loss through the backfire screens used in the present investigation. During the runs with the NACA auxiliary-stage inlet elbow, 1325 brake horsepower was obtained at an auxiliary-stage tip speed of 1235 feet per second, an increase of 29 horsepower over the results of the first run. When the standard interstage duct was replaced with that designed at the NACA, a maximum of 1335 brake horsepower was obtained, which is about 39 horsepower over the results of the first series of runs and about 25 brake horsepower over the results obtained in reference 1. The highest manifold pressure obtained during the three series was 55.6 inches of mercury absolute. This value was obtained in the third series at an auxiliary-stage tip speed of 1235 feet per second. Because a pressure loss of slightly more than

RESTRICTED

RESTRICTED

2 inches of mercury through the backfire screens existed at the test point, this manifold pressure is 0.5 inch lower than that obtained at the same engine condition in reference 1.

Mixture temperature (fig. 7) is about 15° F lower than that obtained in reference 1 because the aftercooler coolant-in temperature was dropped to a value of 105 ±5° F in order to approximate flight conditions. This drop in mixture temperature, which had a beneficial effect on the engine performance, together with the pressure drop through the backfire screens prevents an exact comparison of these results with those of reference 1.

Engine fuel and air flow vary linearly with auxiliary-stage tip speed for the entire range of the investigation, as shown in figure 8. The induction system did not reach a point of critical flow, as shown by the fact that the air-flow curves are linear and do not begin to level off.

With the NACA-designed auxiliary-stage supercharger inlet elbow, a definite increase in engine performance was obtained over the results with the standard Bell elbow. The NACA elbow did not have a screen as did the standard elbow, but from the flow tests of the Bell and the NACA elbow (reference 3) it was found that the pressure loss through the standard elbow with the screen removed was twice as large as that through the NACA elbow. A slight increase in air flow at high tip speeds is evident for the runs with the NACA duct.

Supercharger Performance

Volume flow and load coefficient. - The auxiliary-stage inlet volume flow increased linearly with auxiliary-stage tip speed (fig. 9) for all runs. The auxiliary-stage volume flow with the parabolic rotating guide vanes reached a maximum value of 90 cubic feet per second at an auxiliary-stage tip speed of 1235 feet per second, which is about 3 cubic feet per second higher than was obtained in reference 1. A further increase in the auxiliary-stage volume flow of approximately 4 cubic feet per second was obtained during the series of runs with the NACA inlet elbow and interstage duct. The engine-stage volume flow increased slightly to a value of 45 cubic feet per second for each of the three series of runs. The volume flow through the engine-stage supercharger is about 2 cubic feet per second lower than that of reference 1, which is attributed to the slight increase in auxiliary-stage density ratio.

RESTRICTED

RESTRICTED

With the parabolic inducers, the engine-stage load coefficient agreed very well with the results of reference 1 but the auxiliary-stage load coefficient was slightly higher. A maximum auxiliary-stage load coefficient of 0.24 cubic foot per revolution was obtained at an auxiliary-stage tip speed of 1235 feet per second with the NACA inlet elbow and interstage duct. The engine-stage load coefficient increased with auxiliary-stage tip speed to a value of 0.11, which agreed very well with the results of reference 1.

Pressure ratio. - Auxiliary-stage, engine-stage, and over-all pressure ratio are plotted against auxiliary-stage tip speed in figure 10. The auxiliary-stage pressure ratios for all three series of runs follow the same general curve. The curves for the auxiliary-stage and engine-stage pressure ratios are practically coincident with those of reference 1. The over-all pressure ratio (the ratio of the total pressure in the center main manifold to the total pressure at the inlet of the auxiliary stage) reaches a peak value of 4.9 at an auxiliary-stage tip speed of 1235 feet per second with the NACA inlet elbow and interstage duct; a gain in pressure ratio of about 0.10 over the pressure ratio at a corresponding point in reference 1 is thus achieved. At the low tip speeds, however, the pressure ratios of reference 1 are slightly higher than those of this investigation.

Temperature rise. - The auxiliary-stage, engine-stage, and over-all temperature rise (fig. 11) follow the same general trends as the pressure ratios and also exhibit the same agreement for each run. The auxiliary-stage temperature rise increases with tip speed to a maximum value of 221° F, which is approximately 5° F lower than the maximum temperature rise obtained in reference 1. Because the pressure ratio for this point is slightly higher than for the corresponding point of reference 1, this drop in temperature rise can be directly attributed to the use of the parabolic rotating guide vanes on the auxiliary-stage supercharger. The engine-stage temperature rise at a tip speed of 1235 rpm is 10° F higher than the temperature rise of reference 1. Because the pressure ratios at this point are equal, this excess temperature rise indicates that the use of the parabolic rotating guide vanes on the present engine-stage impeller is actually detrimental. The over-all temperature rise reaches a value of 357° F, which is about 5° F higher than was obtained with the standard rotating guide vanes (reference 1).

Adiabatic efficiency and pressure coefficient. - At tip speeds greater than 1000 feet per second, the auxiliary-stage supercharger shows a gain of about 2 points in adiabatic efficiency (fig. 12) over

RESTRICTED

RESTRICTED

the results of reference 1. This gain in efficiency follows directly from the fact that the temperature rise is lower than that of reference 1 and the pressure ratio is slightly higher.

The engine-stage adiabatic efficiency is about 10 points lower than that of reference 1 mainly because of the greater temperature rise for the same pressure ratio and the correction factor added to the manifold temperature. This correction factor is only approximate, so the values for engine-stage and over-all adiabatic efficiency should therefore be considered only as a trend.

The auxiliary-stage pressure coefficient (fig. 13) follows the same general trend as the adiabatic efficiency and agrees fairly well with the results of reference 1. The engine-stage pressure coefficient is from 3 to 7 points lower than the pressure coefficient of reference 1, which is a direct result of the lower auxiliary-stage temperature rise of the present investigation.

As pointed out in reference 3, the auxiliary-stage supercharger operates at a higher value of load coefficient than the value necessary for maximum efficiency at high auxiliary-stage impeller tip speeds. Thus, the increase in volume flow obtained with the modifications will cause the supercharger to operate at a less efficient value of load coefficient. As a result, the full beneficial effect of the parabolic rotating guide vanes and revised ducting on the supercharger efficiency may not be realized.

When the inlet Mach number and the load coefficient of the auxiliary-stage supercharger of the full-scale engine tests were known, it was possible to obtain the results for corresponding points from reference 5, which were obtained at ambient inlet-air temperatures. The tests of reference 5 were made with an elbow inlet and also with an axial inlet to the auxiliary-stage supercharger. A comparison of the auxiliary-stage supercharger data of the present full-scale engine investigation and the variable-component tests of reference 5 is made in the following table:

RESTRICTED

RESTRICTED

Load coefficient	Supercharger Mach number	Full-scale engine with parabolic rotating guide vanes and NACA inlet elbow		Variable-component supercharger test rig with standard rotating guide vanes			
				Inlet elbow		Axial inlet	
		Adiabatic efficiency	Pressure ratio	Adiabatic efficiency	Pressure ratio	Adiabatic efficiency	Pressure ratio
0.214	0.767	0.62	1.56	0.70	1.59	0.70	1.59
.215	.863	.67	1.82	.71	1.82	.72	1.83
.219	.989	.71	2.19	.71	2.15	.72	2.15
.223	1.05	.72	2.40	.69	2.38	.72	2.39
.226	1.12	.72	2.66	.69	2.64	.70	2.64

The pressure ratios for the full-scale investigation are slightly higher at the high supercharger Mach numbers than the values obtained from the variable-component investigation. Because the difference is so slight, however, it may be due to the difference in the location of measuring stations in the two setups. The greatest difference among the three series of runs is noted in the values for adiabatic efficiency. For the low Mach numbers, the adiabatic efficiencies from the full-scale runs are noticeably lower than the values from the variable-component runs. This difference can be attributed to the difference in the inlet temperatures for the two runs. As shown in reference 6, a decrease in inlet temperature causes the efficiency to be markedly reduced, particularly at the low tip speeds. At the higher Mach numbers, the adiabatic efficiencies of the full-scale runs agree very well with the values from the variable-component runs with an axial inlet and are slightly higher than the values from the variable-component runs with an inlet elbow, which indicates that a definite gain in performance at the high supercharger Mach numbers is obtained by the use of the parabolic rotating guide vanes on the auxiliary-stage impeller.

SUMMARY OF RESULTS

From an investigation to determine the effect of modifications to the induction system on altitude performance of the V-1710-93 engine, the following results were obtained:

RESTRICTED

RESTRICTED

1. An increase of 25 horsepower resulted from modifying the engine by incorporating parabolic rotating guide vanes on the superchargers, using an NACA-designed inlet elbow and interstage duct, and inserting backfire screens behind the aftercooler.

2. Modifying the engine by incorporating backfire screens and by using parabolic rotating guide vanes on both superchargers gave no over-all power increase. Although the performance of the auxiliary-stage supercharger was improved, the gain was nullified by the pressure drop through the backfire screens and by the concurrent decrease in performance of the engine-stage supercharger.

3. Replacing the standard Bell inlet elbow with one designed by the NACA resulted in a power increase of about 15 brake horsepower. This power increase can be attributed to the fact that the pressure losses in the NACA-designed inlet elbow were approximately one-half those for the standard Bell elbow.

4. The use of the NACA-designed interstage duct gave an additional power increase of about 10 brake horsepower.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

Raymond M. Standahar,
Mechanical Engineer.

James S. McCarty,
Mechanical Engineer.

Approved:

Oscar W. Schey,
Mechanical Engineer.

va

RESTRICTED

RESTRICTED

REFERENCES

1. Standahar, Raymond M., and Mizisin, John: Effect of Modifications to Induction System on Altitude Performance of V-1710-93 Engine. I - Effect of Increased Supercharging, Interstage Carburetor, Aftercooling and Internal-Coolant Injection. NACA MR No. E6E20, Army Air Forces, 1946.

2. Standahar, Ray M., and Schum, Harold J.: Effect of Modifications to Induction System on Altitude Performance of V-1710-93 Engine. II - Effect of Increase in Engine Speed from 3000 to 3200 rpm. NACA MR No. E6F07, Army Air Forces, 1946.

3. Todd, Donald J., and Graper, Fred: Effect of NACA and Bell Standard Inlet Elbows on Performance of Auxiliary-Stage Supercharger with Parabolic Guide Vanes for Allison V-1710 Engine. NACA MR No. E6B21, Army Air Forces, 1946.

4. Ellerbrock, Herman H., Jr., and Goldstein, Arthur W.: Principles and Methods of Rating and Testing Centrifugal Superchargers. NACA ARR, Feb. 1942.

5. Klein, Harold, and Downing, Richard, M.: Tests of an Allison Auxiliary-Stage Supercharger for a V-1710-93 Engine. NACA Memo. rep., Army Air Forces, April 15, 1944.

6. Downing, Richard M., and Finger, Harold B.: Comparison of the Sea-Level and Altitude Performance of the Auxiliary-Stage Supercharger of the V-1710-93 Engine. NACA MR No. E6H07, Army Air Forces, 1946.

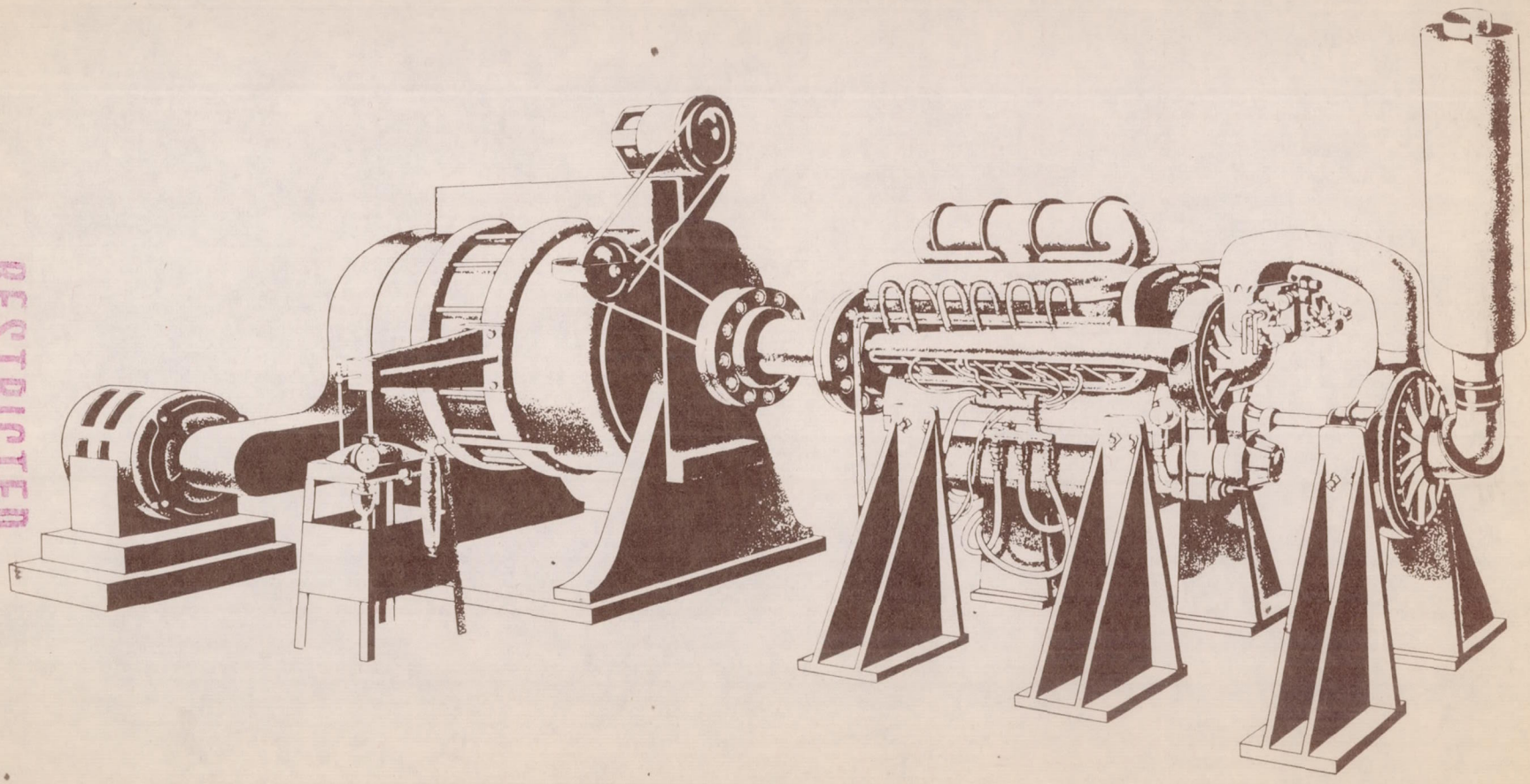
RESTRICTED

48+325

700

RESTRICTED

RESTRICTED



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 1. - Test setup for V-1710-93 engine with modified induction system.

46+97 700

RESTRICTED

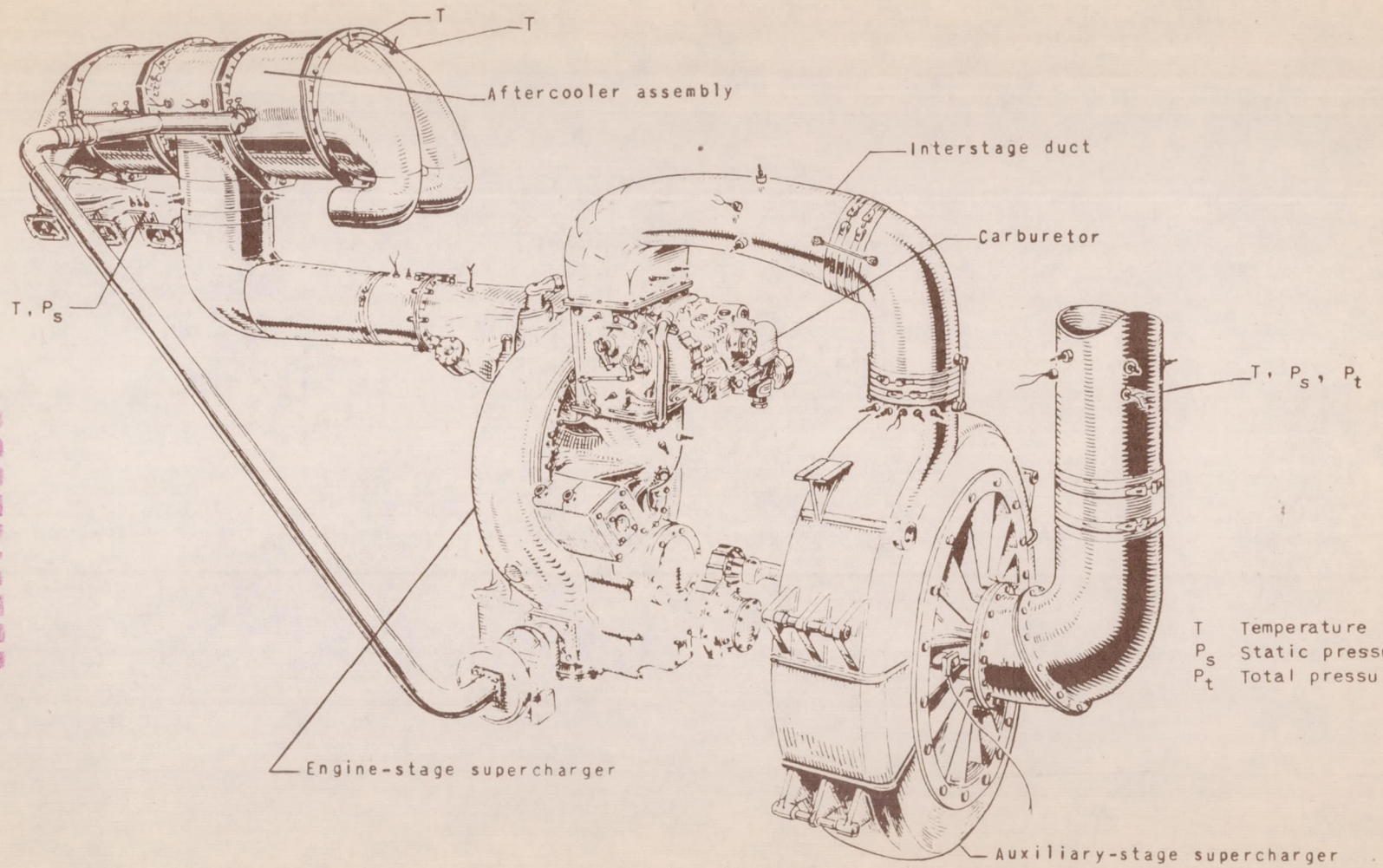


Fig. 2

Figure 2. - Instrumentation for induction system of V-1710-93 engine.

RESTRICTED

RESTRICTED

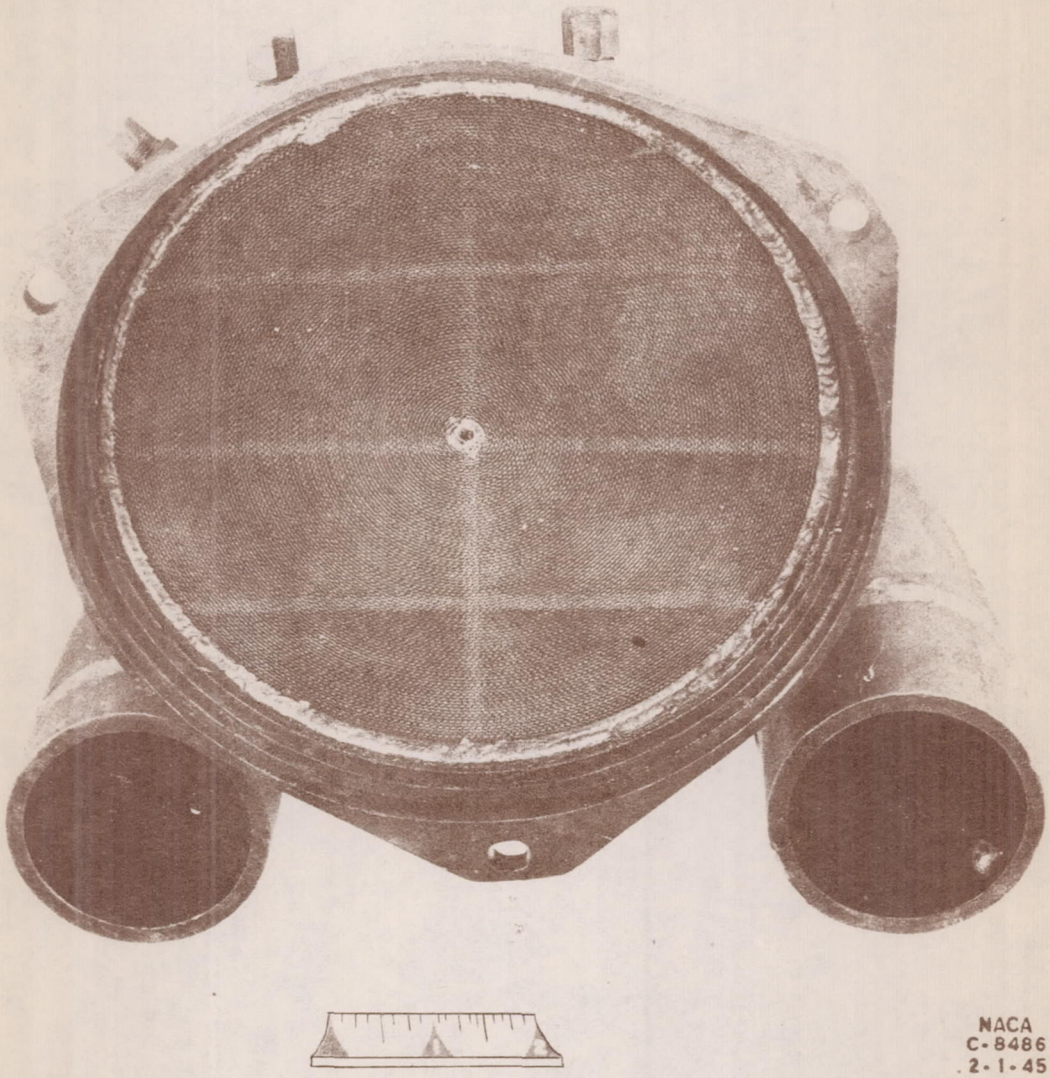


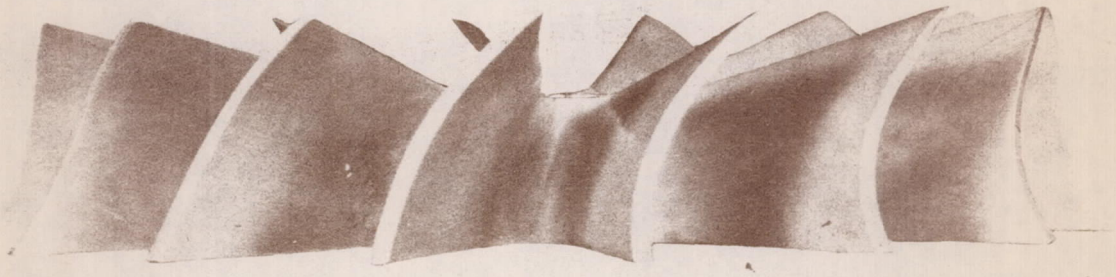
Figure 3. - Backfire screen in aftercooler-outlet duct.

RESTRICTED

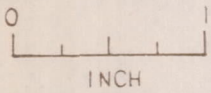
RESTRICTED



(a) Standard.



(b) Parabolic.



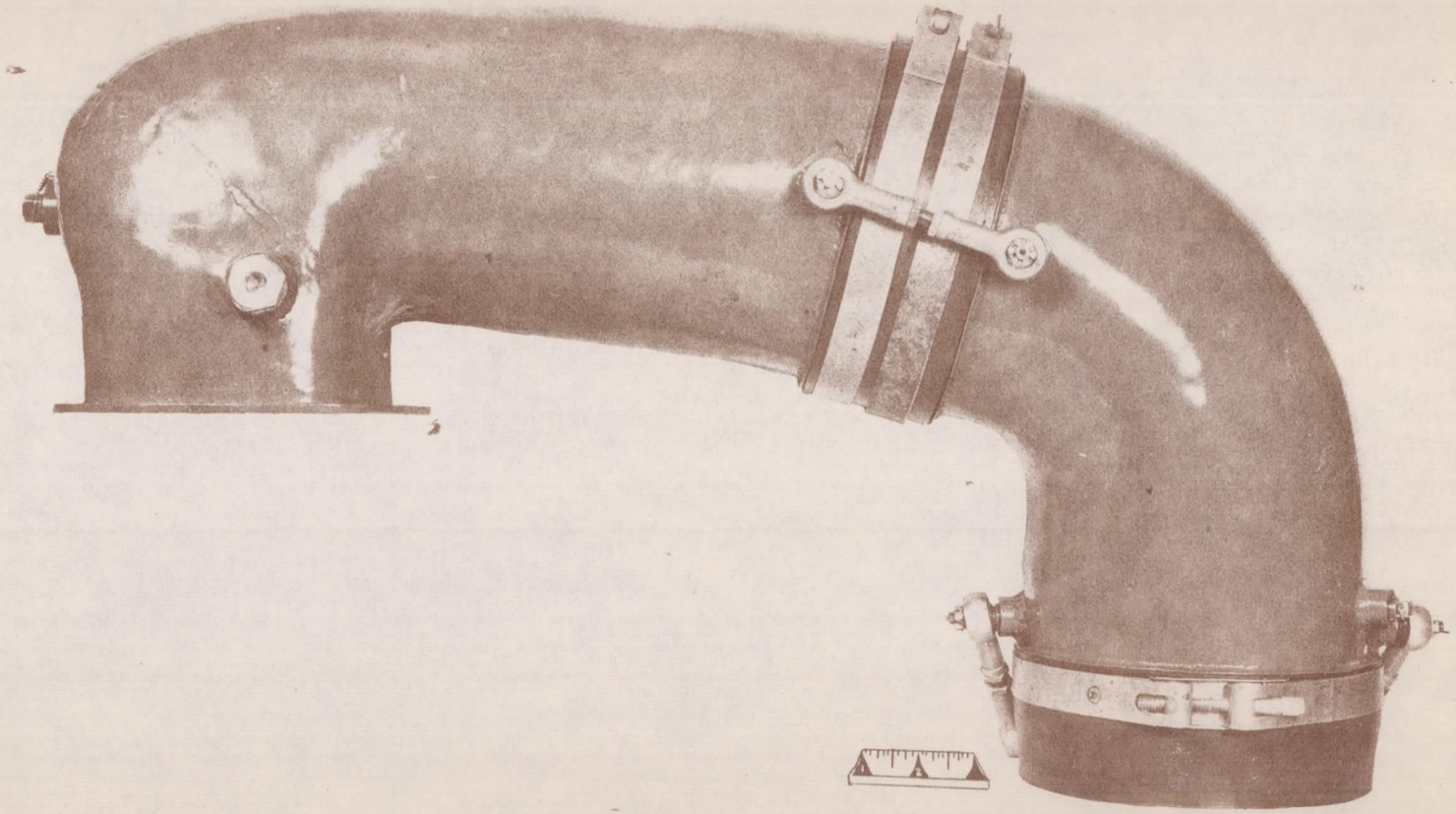
NACA
C-10079
5-16-45

Figure 4. - Comparison of standard and parabolic rotating guide vanes.

RESTRICTED

RESTRICTED

RESTRICTED



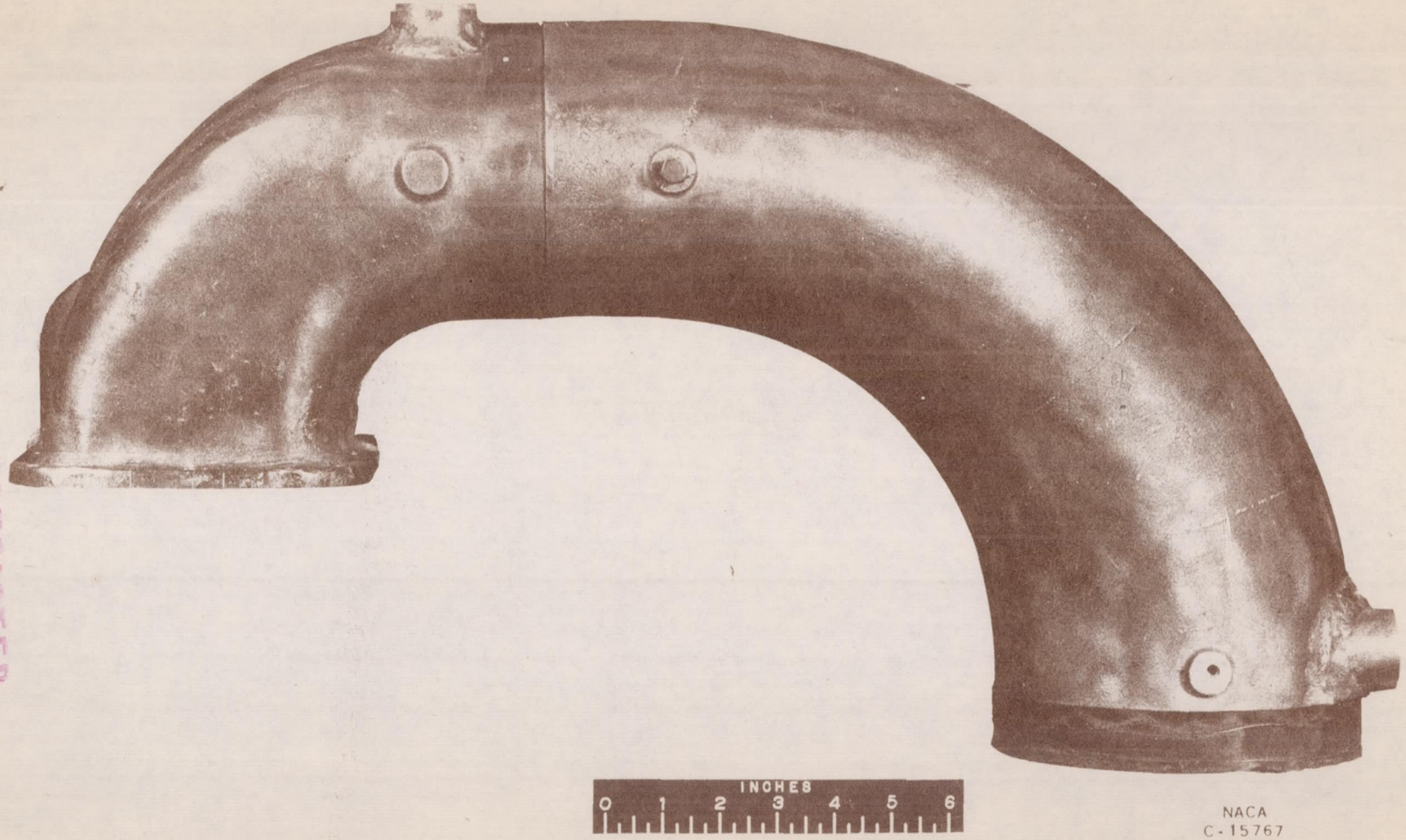
NACA
C-5185
6-10-44

(a) Standard interstage duct.

Figure 5. - Comparison of two interstage ducts for V-1710-93 engine.

RESTRICTED

RESTRICTED



(b) NACA-designed interstage duct.

Figure 5. - Concluded. Comparison of two interstage ducts for V-1710-93 engine.

RESTRICTED

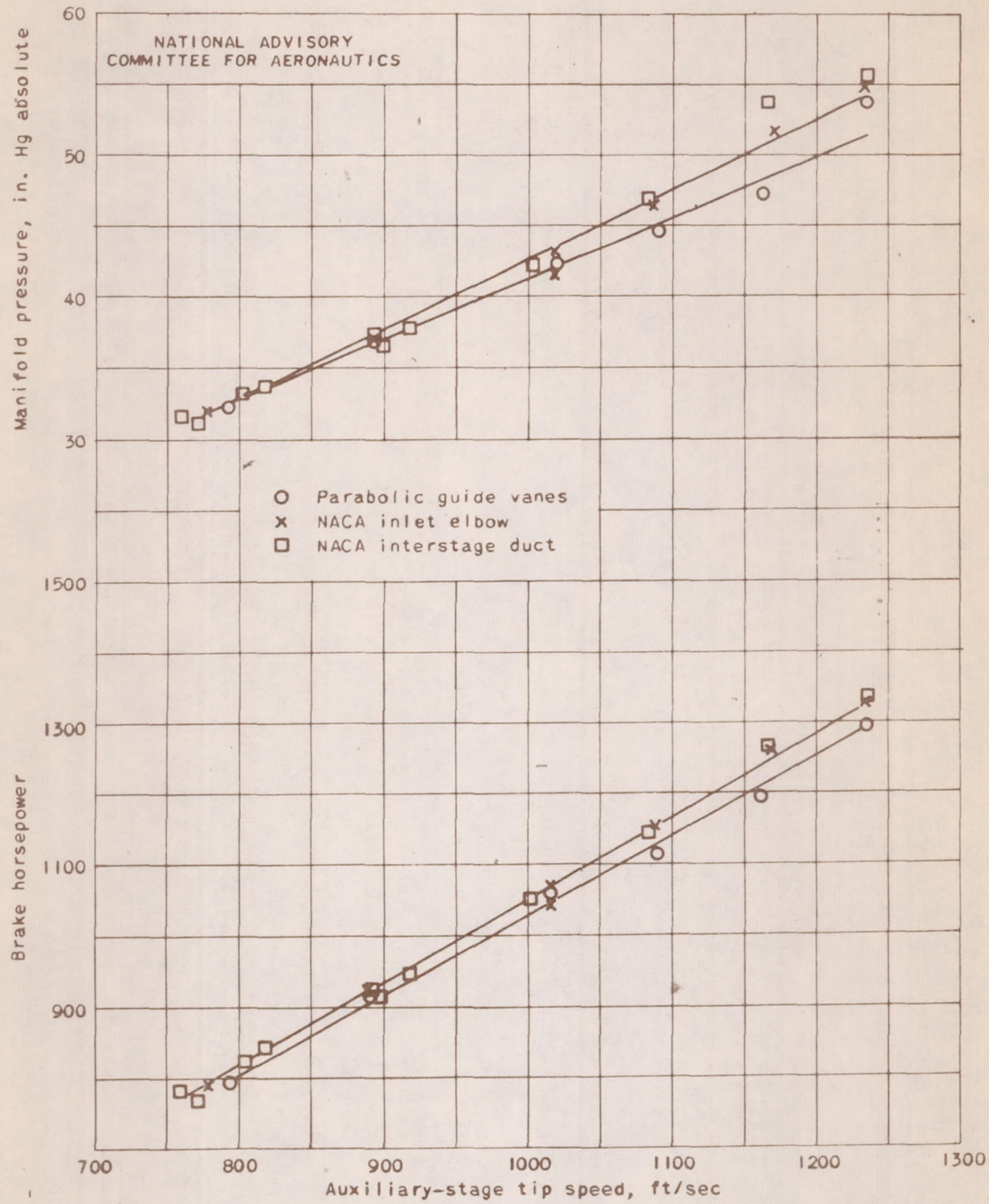


Figure 6. - Brake horsepower and manifold pressure of V-1710-93 engine with modified induction system.

RESTRICTED

RESTRICTED

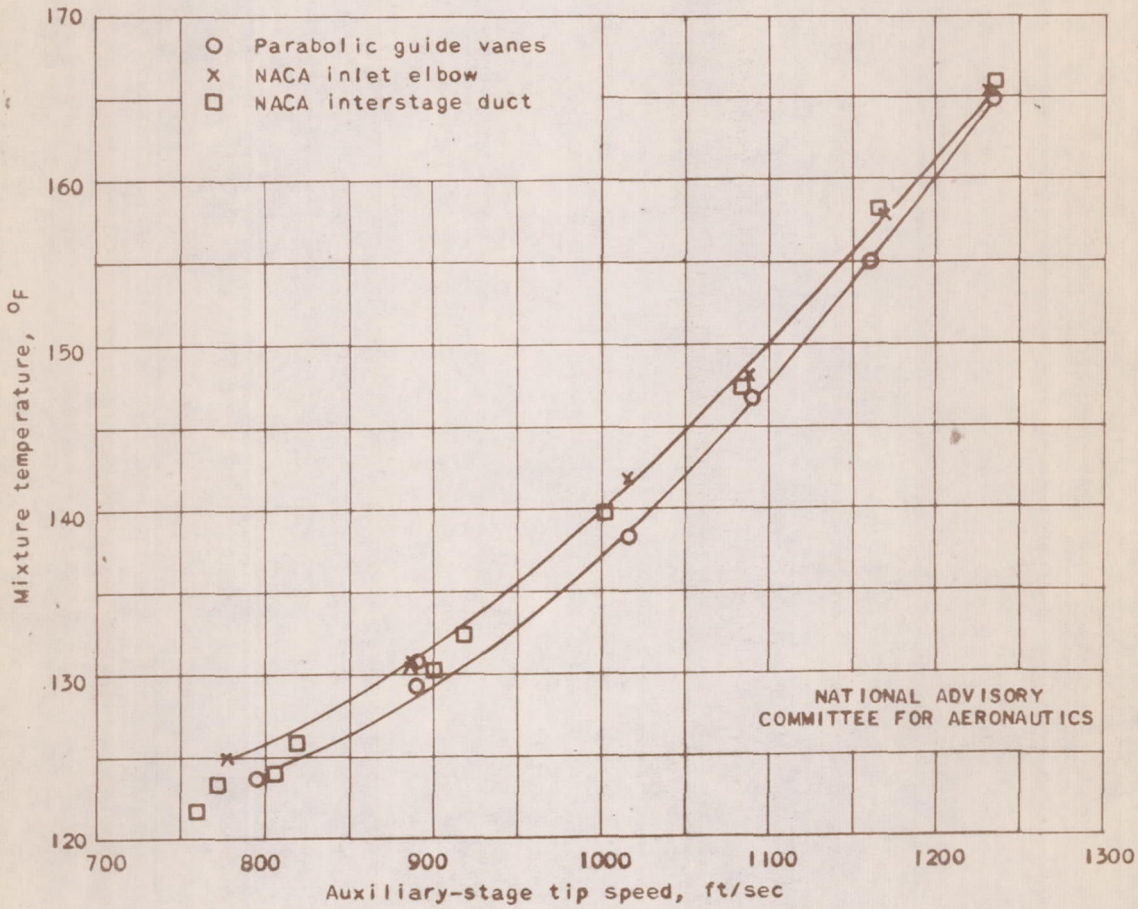


Figure 7. – Mixture temperature of V-1710-93 engine with modified induction system.

RESTRICTED

RESTRICTED

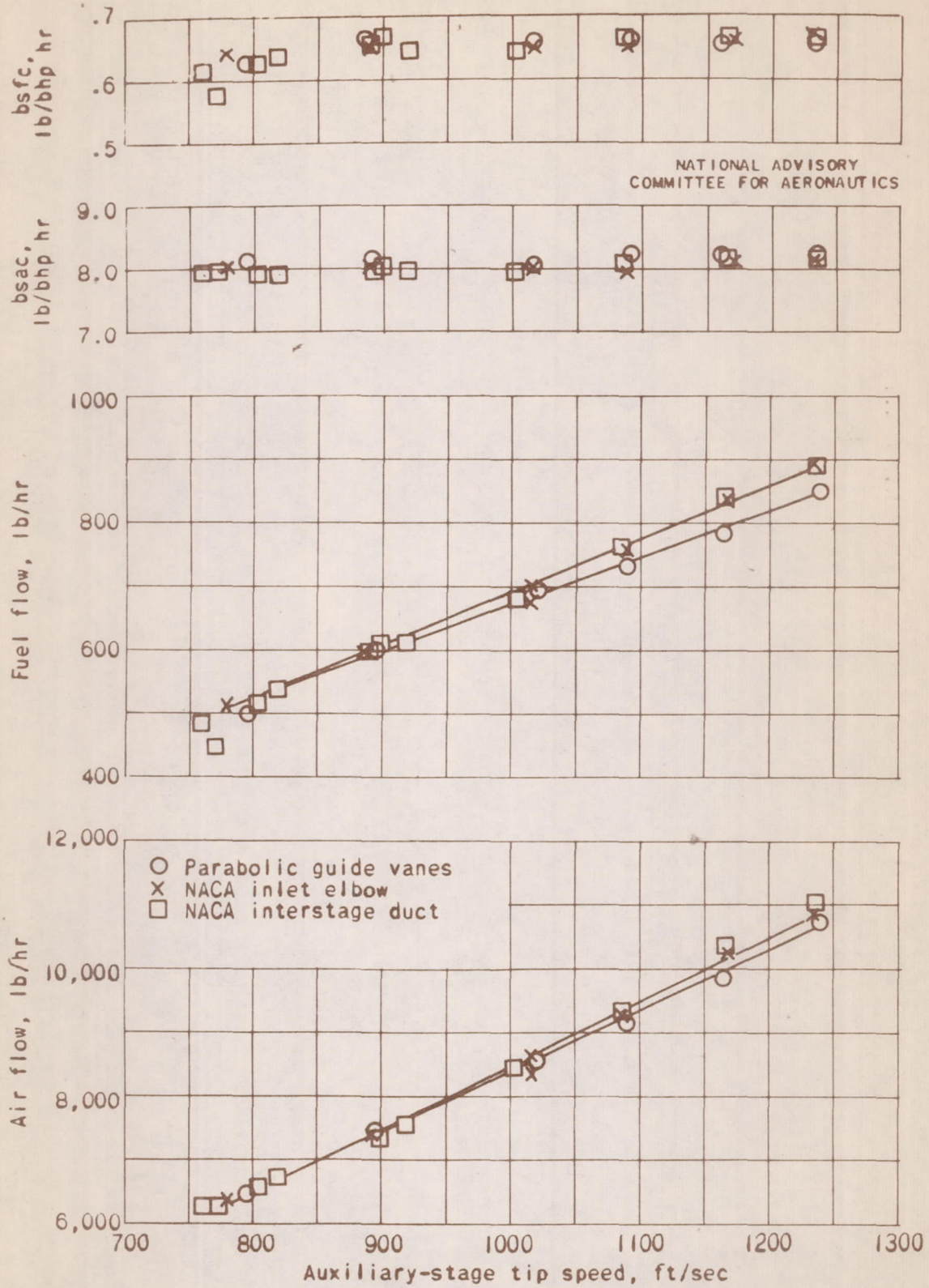


Figure 8. - Fuel and air flow of V-1710-93 engine with modified induction system.

RESTRICTED

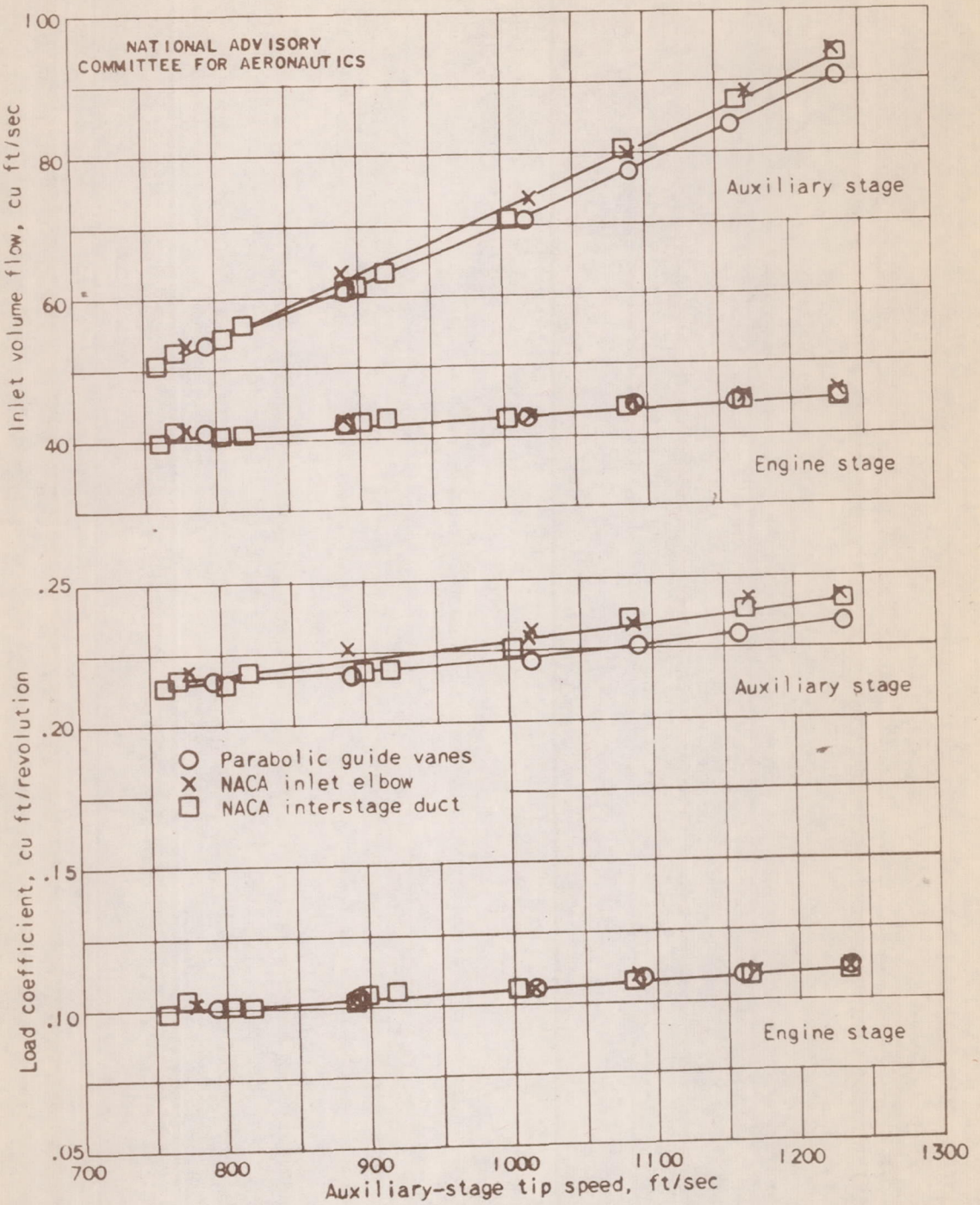


Figure 9. - Supercharger load coefficient and inlet volume flow of V-1710-93 engine with modified induction system.

RESTRICTED

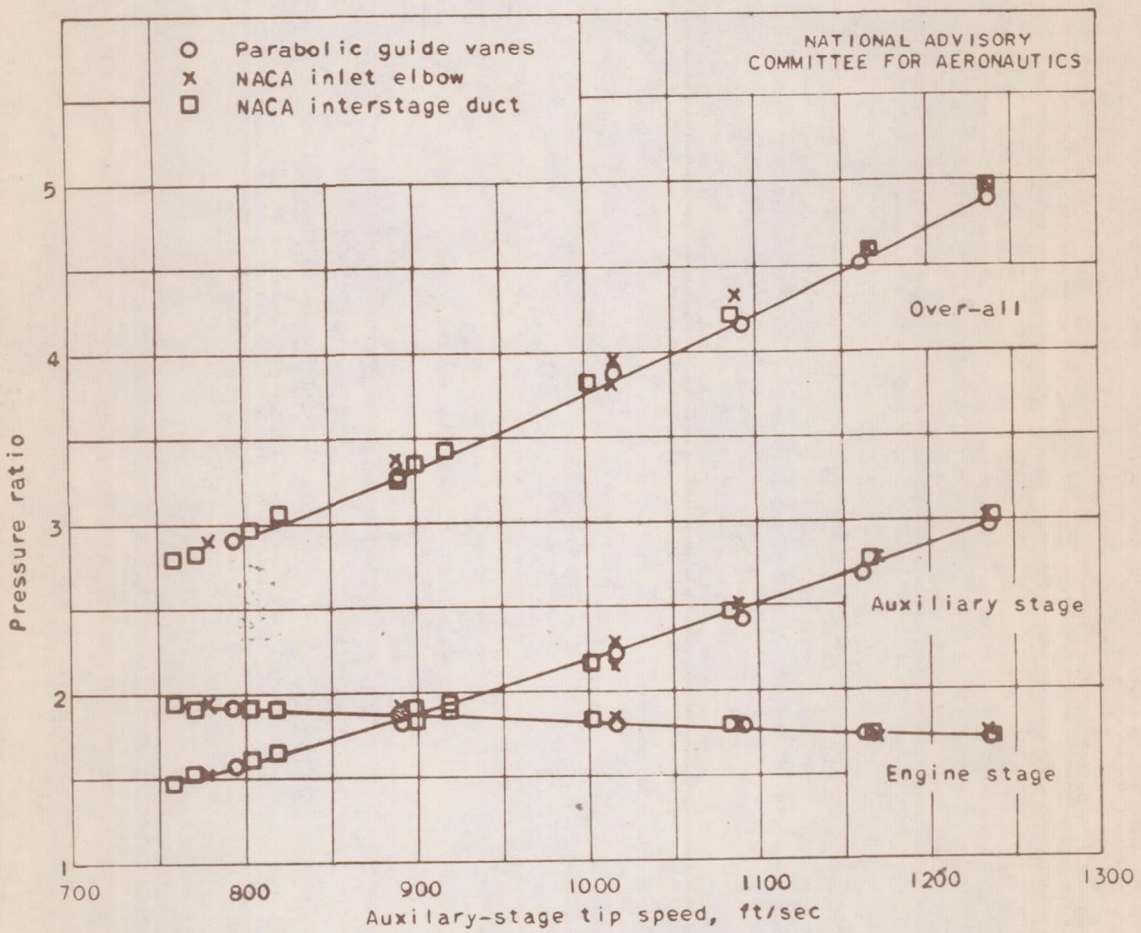


Figure 10. - Pressure ratios of two-stage supercharger of V-1710-93 engine with modified induction system.

RESTRICTED

RESTRICTED

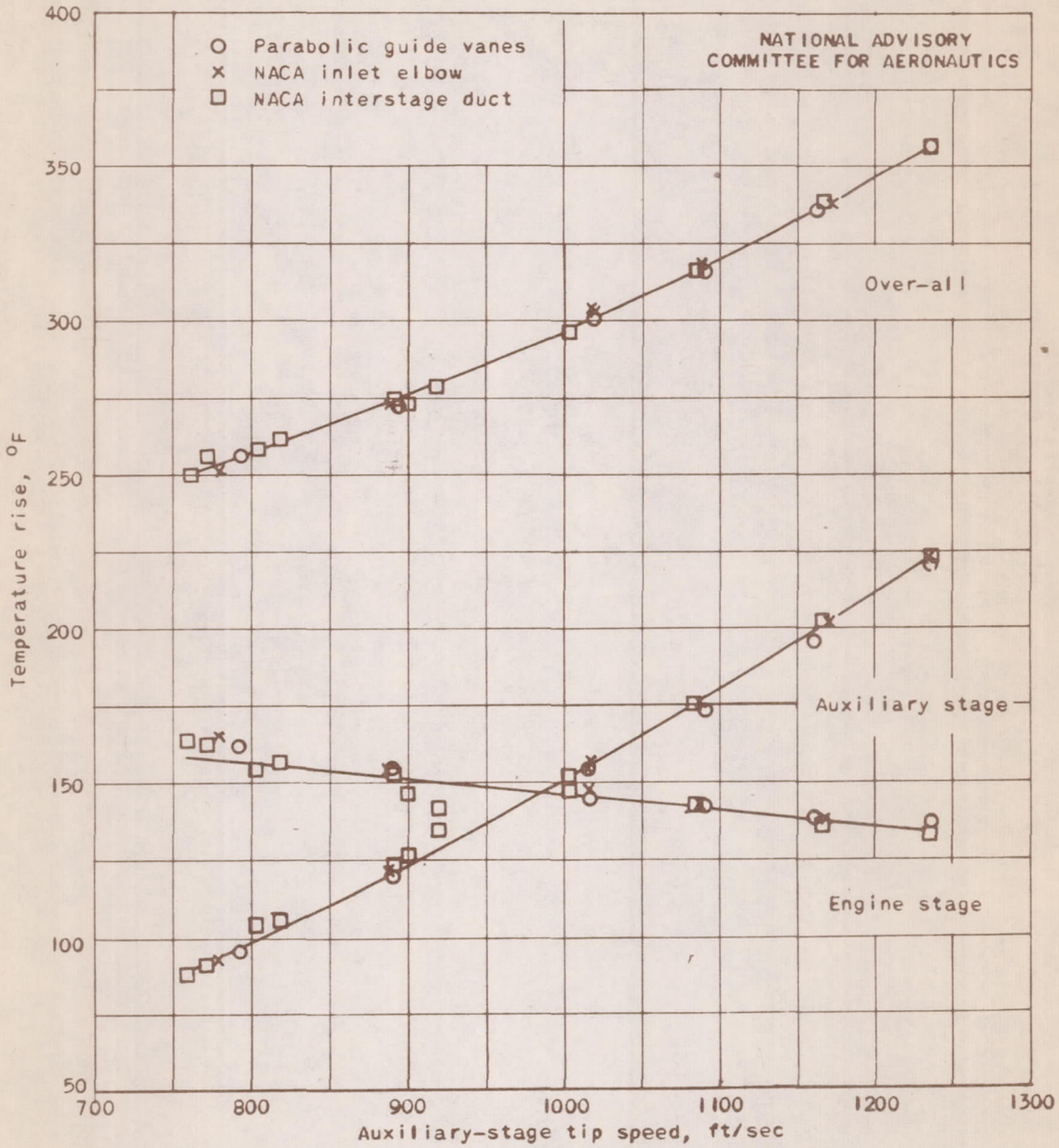


Figure 11. - Temperature rise through two-stage supercharger of V-1710-93 engine with modified induction system.

RESTRICTED

RESTRICTED

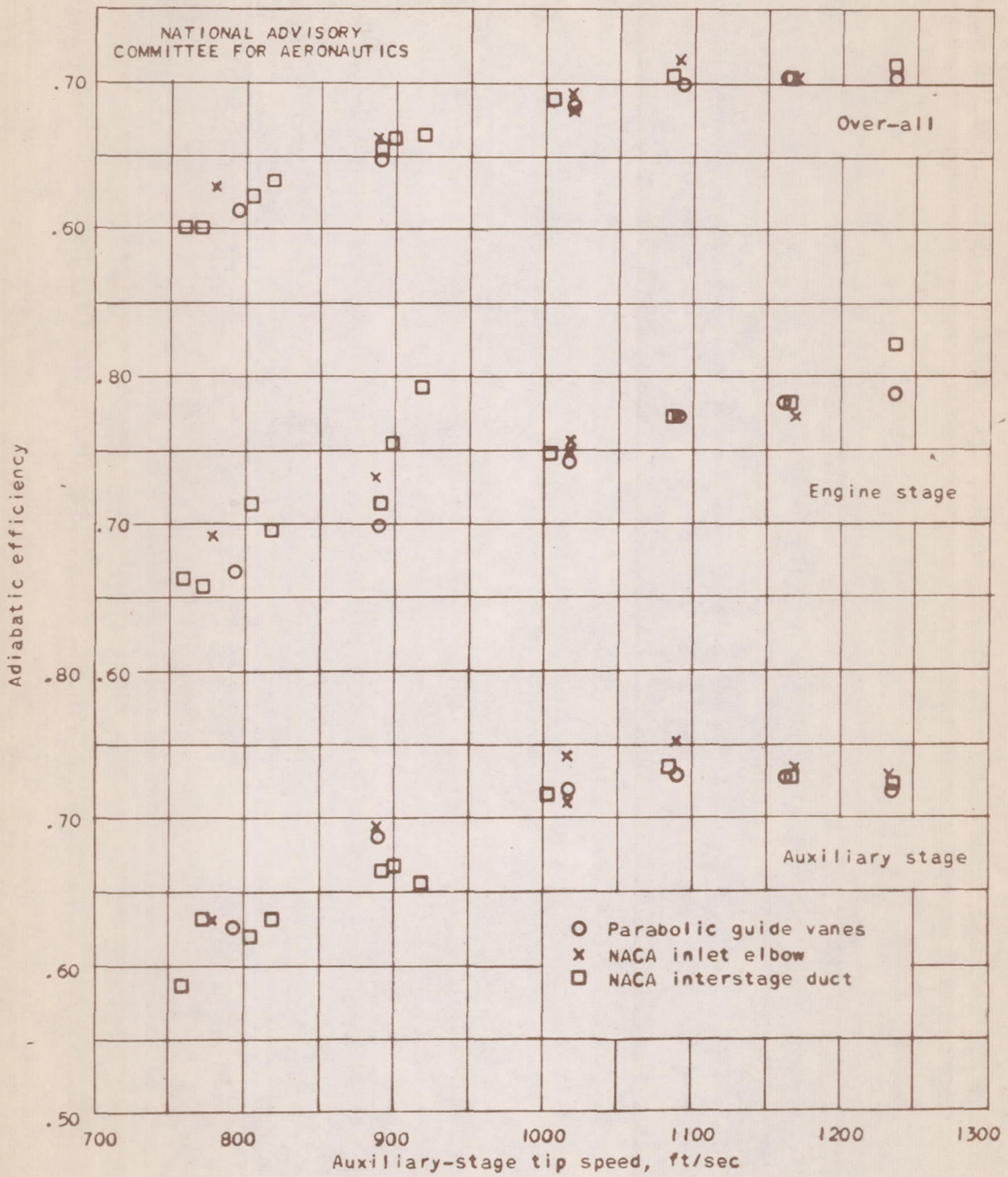


Figure 12. - Adiabatic efficiencies of two-stage supercharger of V-1710-93 engine with modified induction system.

RESTRICTED

RESTRICTED

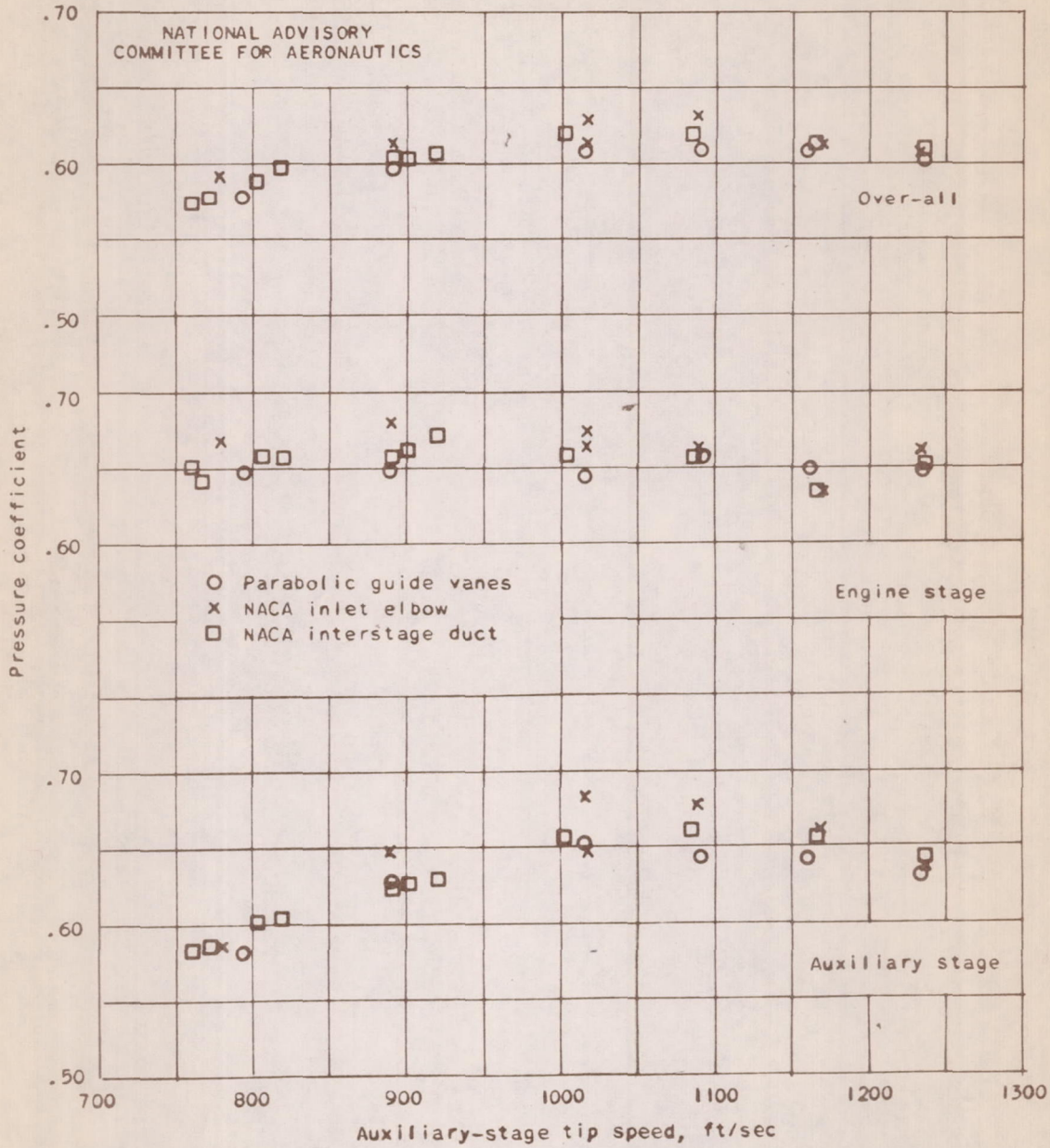


Figure 13. - Pressure coefficients of two-stage supercharger of V-1710-93 engine with modified induction system.

RESTRICTED

UNCLASSIFIED

UNCLASSIFIED